International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 1, Feb 2018, 557-568

SURFACE DEFORMATION: A SOFTWARE AND HARDWARE VALIDATION & ANALYSIS

SMT. MAYA V. LAKHA[1] & K. CHENNAKESAVA REDDY[2]

[1]*Research Scholar, Department of ECE, Jawaharlal Nehru Technological University, Hyderabad, Telangana India*

[2]*Research Supervisors, Department of ECE, Jawaharlal Nehru Technological University, Hyderabad, Telangana India*

ABSTRACT

The present day techniques and machinery used in automobile industry to assess the useful lifespan of an object are high end, heavy and expertise oriented. Away from these conventional and not so user friendly approaches, an illustrative attempt has been made in this paper wherein a low-cost machine vision system with image processing is designed for surface deformation inspections and thereby to assess the lifespan of the objects. Machine vision systems provide quality control and real-time feedback for industrial processes, overcoming physical limitations and subjective judgment of humans. The work is based on the concept of pattern recognition, since these patterns can be intelligently used and algorithmically designed to address many issues. The present day techniques such as light interferometer, choreography, holography etc. require excellent expertise, whereas the presented work requires just the basics and the proposed method can be seen as a combination of all advanced systems involving optical and image capturing principles.

KEYWORDS: NDT, SVD, Holography, Shearography, Machine Vision & Surface Deformation

Received: Dec 02, 2017**; Accepted:** Dec 23, 2017**; Published:** Jan 12, 2018**; Paper Id.:** IJMPERDFEB201862

Original Article

INTRODUCTION

The use of statistical pattern recognition dates from 1950s and, although it is not one of the main topics of image processing research, it provides an important background - especially in the area of automated visual inspection where decisions about the adequacy of the products have to be made constantly. On the other hand, real industrial applications of texture description and recognition are becoming more and more common. During the last two decades, the improvement in image processing with microcomputers has caused non-contact measurement techniques to become more and more popular in the experimental mechanics community. Some full-field measurement techniques like interferometry or photo elasticimetry were known and used beforehand. These techniques suffered, however from the non-automatic processing of the fringe patterns they provided, leading to some heavy, boring and unreliable by-hand manipulations before obtaining relevant information in terms of displacement or strain. In the recent past, thanks to the dramatic advances in microcomputer and camera technology, many research groups devoted to optics, experimental mechanics or data processing have been developing suitable techniques based on the use of optical devices, digital cameras, algorithms and softwares which automatically process images. These techniques directly provide displacement or strain contours onto specimens under testing. Temperature fields are also available, thanks to infrared scanning cameras. Such measurements constitute in fact, a new type of tool for researchers in mechanics of solids, which is especially interesting in the field of composite material characterization. Indeed, composites present some features like heterogeneities at different scales which render such full field measurements very attractive.

Keeping all these aspects in mind, an adoptive and simple technique has been devised in this paper and the work takes advantage of the fact that every image is having a well known singular value matrix which can be resolved easily to analyze various aspects

LITERATURE OVERVIEW

The most relevant review articles are considered here such as the one in the year **(2006)[7] Francesco Braghin et al.,** combined a mathematical model along with experimentally determined local friction law and wear law in the paper “Tire Wear Model: Validation and Sensitivity Analysis”. The work presents a simulation tool that takes into account both tire structure and tire thread design allowing to predict tire wear for a given manoeuvre as a function of road and vehicle characteristics. The methodology predicted the tire wear both qualitatively and quantitatively by generating virtual tires for numerical analysis. The sensitivity analysis showed that the thread compound properties are the ones that mostly affect the slip distribution inside the contact footprint and thus wear behavior of the tire. The increase in thread compound density, stiffness and damping lead to reduction of tire wear by around 15-30% but the only fact that the tire wear and friction properties must be always be constant. In the year **(2013)[12] P Huke el al** proposed optical non destructive testing method in his paper “Novel trends in optical non-destructive testing methods” wherein he proposed the system to measure hidden defects in the objects by using beams of ray. This system worked well but, suffers because of heavy machinery requirements, skilled manpower requirement, Numerical calculations and scattering of rays at edges. In the year **(2014)[3] Khalid B Najim** presented a paper “can image processing technique be used as a non-destructive test in predicting concrete compressive strength” wherein he proposed advanced ultrasonic pulse velocity method to assess the compressive strength of concrete but, he failed to come up with a conclusion due to objects composite nature**. Yair Wiseman (2015)[6]** presented a technique using digital camera with JPEG format in his paper “Take a Picture of Your Tire!” The based on the assessment of accidents due to damaged cars per year (nearly 10,000 fatalities each year only in US). A JPEG model was proposed which uses color transformation, quantization and Huffman coding for image compression. It evaluated the method for taking pictures of damages tires just by rolling them over but the author admitted that more practical approach might have been better since it is a static approach. **SangBock Lee (2016)[1]** presented an image processing algorithm in his paper “Image Processing Algorithm for Non- destructive testing“. The paper demonstrated that the readability of the images acquired by a mobile digital radiographic testing device. The algorithm is developed on visual C++ which selects internal region in the acquired images and then applies a thinning process based on Sobel operators to the selected region. The algorithm makes readable the defect parts which are not visible to the naked eyes. The only drawback is that it is applicable only for static measurements. **Sze-Vei khoo et al. (2016)[2]** presented views on digital image correlation techniques in the paper “A review of surface deformation and strain measurements using two dimensional digital image correlation”. In the paper digital image correlation (DIC) refers to a non-contact strain measurement method that mathematically compares the grey intensity changes of the images captured at two different states: before and after deformation. The technique correlates many types of patterns such as grids, dots, lines and random patterns. The method correlates if and only if surface pattern exhibit isotropic behavior but fails if it not and it shows problems from 2D to 3D pattern orientation.

The reviews suggest development of a novel technology since the previous works suffers limitations of static type of measurements, format orientation, composite nature of materials, colored complexities, selection of constant parameters, material locations, rate of inflation, limitations of image processing processes such as edge selections and the works require

more practical approach. The ultimate previous methods require a large number of strain gauges or transducers for measurements. Ultrasonic methods detect flaws by identifying in homogeneities in the object and do not provide direct information on the criticality of the flaws. The holographic methods requires reference beam which cannot be made constant under environmental conditions. Shearography methods stress the object and thereby make the material to reveal flaws. Exact duplication of the actual stress-increment for testing is not possible and is difficult therefore various other means must be developed and the proposed method is one among them.

EXISTING TECHNOLOGY

The immediate descendant for the proposed technique is Interferometric methods such as HOLOGRAPHY and SHEAROGRAPHY. Laser beams are used in Holograpgy and Shearography to get Image patterns. Laser beams have the ability of destructive and constructive interference. **Holography** is used for surface displacement measurements. An object is compared with itself in a slightly deformed state. Numerical differentiation is required which is a laborious task and is prone for large numerical errors whereas **Shearography** is used to get strain measurements. It measures derivative of surface displacements. Numerical differentiation is not required. Both Holography and Shearography are not user friendly and requires skilled human interpretation. Other Immediate existing methods are:

Infrared: - Used for Thermal analysis of the tire. The infrared scanning system continuously records temperature gradient and determines “hot spots” and incipient failures. Output is recorded on strip recorders. The drawback is restriction in inspection depth combined with dimension and orientation of defect in material.

Ultrasonic: - This technique is an immersion method wherein the tire is immersed in water and the reflection is got from the non uniform parts. The advantage is that internal defects can easily be detected but, the drawback is that spurious indication which result in unnecessary repairs and a high degree of operator skill and integrity is required.

Microwave:- Uses radar signals to penetrate the tire to detect physical property changes. The technique has the advantage such as good penetration, low cost, good resolution but, suffers from diffraction from the edges of the material and multiple reflections.

X-Ray:- Used to detect the hidden areas by ray penetration. It Detects surface and internal flaws. The drawback is that it is very expensive with safety hazard. It is highly directional and sensitive to flaw orientation. High degree of skill required for exposure and interpretation.

The inspiration is drawn from the fact that heavy machinery along with skilled manpower requirement is must for such tests. For example under traditional testing a large number of strain gauges and transducers are required to be mounted on the testing system. The methodology involves use of a simple digital camera and a system with Matlab platform.

PROPOSED METHODOLOGY

Non-destructive tests have the potential to predict performance without destroying the product, to study the mechanism of product performance and to enhance product reliability. Most classical testing techniques are seeking performance limits and consequently result in destruction of the specimen. Considerable effort has been expended to develop nondestructive tests for application alone or in conjunction with standard tests.

The Methodology involves two operations namely software oriented gray level change analysis and hardware oriented physical temperature measurements. The first approach is the software simulation which involves noting of gray level changes in the frontal surface of the testing tire. As the tire deforms regularly the gray levels expands. The gray level changes are nothing but singular values which serve as features of the tire. Feature extraction is a process to select important characteristics of an image or object. The second approach is the hardware based temperature observation of the tires at regular intervals and these measurements are then calibrated for good, average and badly deformed tires. As noted the temperatures will be more as the tire deforms regularly. A temperature sensor is used as a noting device. The thread wear and temperature standards which are in use in tire industry are:

Table 1: Tire & Thread Width

Tire Type	Thread Width
Good Tire	10/32" to 11/32"
Average Deformed Tire	6/32” to 8/32”
Badly Deformed Tire	2/32” of remaining thread depth

According to most states' laws, tires are legally worn out when they have worn down to 2/32" of remaining tread depth. The thread life ranges from 30,000 miles to 100,000 miles. Most of small cuts and punctures in the thread area (up to ¼” in size) can be repaired. Every tire requires a break-in periods of 500 miles for optimum performance. To help warn drivers that their tires have reached that point, tires sold have indicators molded into their tread design called "wear bars" which run across their tread pattern from their outside shoulder to inside shoulder. Wear bars are designed to visually connect the elements of the tire's tread pattern and warn drivers when their tires no longer meet minimum tread depth requirements.

Temperature (Resistance) Grades

Temperature Grade indicates the extent to which heat is generated and/or dissipated by a tire. If the tire is unable to dissipate the heat effectively or if the tire is unable to resist the destructive effects of heat buildup, its ability to run at high speeds is reduced.

The grade is established by measuring a loaded tire's ability to operate at high speeds without failure by running an inflated test tire against a large diameter high-speed laboratory test wheel.

Table 2: Temperature and Speed Grades

Temperature Grades	Speeds in mph
A	Over 115
B	Between 100 to 115
C	Between 85 to 100

Every tire sold must be capable of earning a "C" rating which indicates the ability to withstand 85 mph speeds. The Temperature ranges from 20^0 C to 80^0 C under ambient temperatures. Thermocouples are often used to record tire temperatures during tire testing.

DESIGN APPROACH

Due to the complexity of the classification problem, a modular approach is adopted whereby the system was separated into smaller individual stages. Each stage in the designed architecture performs an intermediate task before

integrating the modules into a complete system. The Module developed performs three major tasks – pre-processing of given test image, extracting the features, and performing classification for the given test sample. The developed classification system is shown in figure below:

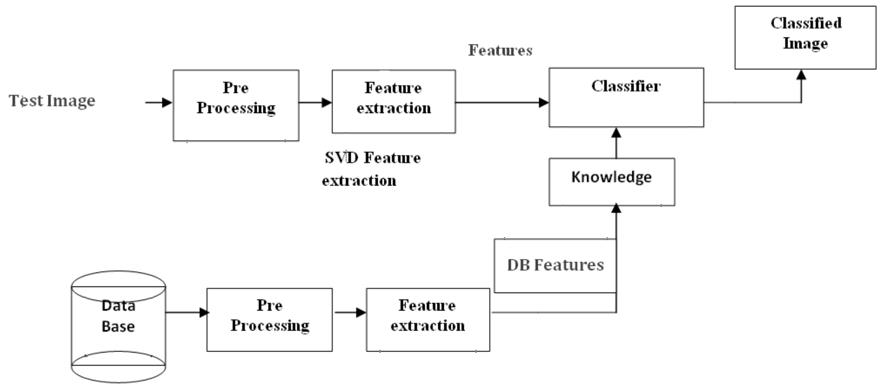


Figure 1: Block Diagram

The Test image can be picked up randomly and is preprocessed i.e., image is transformed to gray (if the image is color), resized to uniform dimension (128x128), and converted into double precision format so that it is brought into operational compatible format. The image is then passed for feature extraction wherein U, V, S matrix are obtained by the using SVD operation. The obtained features are the Singular Values used as features for classification. These features are passed to the classifier unit for the classification of given test image with the knowledge created for the available database. The classification is done by comparing the weights of the test image with the known weights of the database images. Mathematically Euclidian distance between the test weight and known set of database weights are found and a minimum distance between any pair would symbolize the closest match.

RESULTS AND DISCSSIONS

To validate the result a vehicle tire as a mechanical object has been considered since it deforms regularly. To achieve the objective an ultimate tire, an average weared tire, a badly weared tire is taken. The considered tires grey level changes and temperatures are noted with respect to thread wear depth which is considered as a deformation measurement parameter. The singular values can be seen as a replacement for physical depth measurement techniques and can be treated as a bench mark values for life span assessment of the tires. The physical numerical aspects are compared with simulated results to give out the conclusions. The validation is twofold: one is through physical and second is through simulation. The physical validation measures thread depth and temperature whereas the simulation is for gray level changes of selected tires and finally a conclusion is brought about the usefulness of the tires.

Frontal tire surface is considered at the beginning and as per gray level changes they are classified accordingly. Tire deforms due to tire's rotation, the loading, the tire's structure, the pressure, the surface temperature and tire's material. Deformation changes are possible for every change of inflation pressure from 4 to 27 mm/t.

Tires which have been in use for more than 5 years or more should be carefully inspected periodically for external signs of wear. All tires manufactured more than 10 years previously should be removed from service. To validate the results a database of twelve tires of four different classes are created and five query images are tested and classification is

done according to the SVD algorithm giving out life expectancy of the test tires.

The database contains twelve tire images grouped into four classes each comprising of good, poor and bad tires. The database images are simulated for singular values and the values are maintained as database values.

The query images are also simulated for singular values and as per the algorithmic steps the query tires are classified as good, poor or bad tires. The query images are from class 1 to 5 with different deformations and are simulated to get their life span as per the standards.

Following are the Database Images

CLASS 1: DATABASE IMAGES 1 TO 3

CLASS 2: DATABASE IMAGES FORM 4 TO 6

CLASS 3: DATABASE IMAGES FORM 7 TO 9

CLASS 4: DATABASE IMAGES FORM 10 TO 12

Following are the Test Images

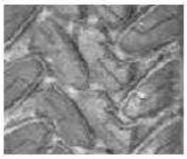
I-IV-OUTSIDE DATABASE V- WITHIN DATABASE

SIMUALTION RESULTS

CASE 1: Test Image 1: Outside Database & Different Class

Test Image

Classified image



Corresponding Simulated Singular values are:

56.683	0	0	0	0	0	0	0	0	0	0	0
0	8.2868	0	0	0	0	0	0	0	0	0	0
0	0	7.4053	0	0	0	0	0	0	0	0	0
0	0	0	6.9001	0	0	0	0	0	0	0	0
0	0	0	0	6.6429	0	0	0	0	0	0	0
0	0	0	0	0	5.549	0	0	0	0	0	0
0	0	0	0	0	0	5.4535	0	0	0	0	0
0	0	0	0	0	0	0	4.8733	0	0	0	0
0	0	0	0	0	0	0	0	4.7838	0	0	0
0	0	0	0	0	0	0	0	0	4.5528	0	0
0	0	0	0	0	0	0	0	0	0	4.4472	0
0	0	0	0	0	0	0	0	0	0	0	4.1732

Classification matrix (difference matrix) for test 1

1	2	3	4	5	6	7	8	9	10	11	12
17.75	19.27	14.05	20.09	20.28	10.74	17.19	18.76	13.92	14.7	11.34	20.96

Sorting Image Matrix for class1 test image 1:

1	2	3	4	5	6	7	8	9	10	11	12
6	11	9	3	10	7	1	8	2	4	5	12

Comments for class 1 test image 1: The nearest recognized image from database is 6 and the Euclidian distance for it is 10.74 which is minimum as compared to other values. The sorted image number is 6. The test image is seen as a average tire and the classified image is also a average tire and hence the life span is approximated up to 50,000 miles with thread width of 6/32” to 8/32” and the temperature observed is 40.5^{0}C to 45.3^{0}C and the.

CASE 2: Test Image 5: Within Database and within Class

Test Image

Classified image

Corresponding simulated singular values are:

65.75	0	0	0	0	0	0	0	0	0	0	0
0	8.628	0	0	0	0	0	0	0	0	0	0
0	0	6.832	0	0	0	0	0	0	0	0	0
0	0	0	5.835	0	0	0	0	0	0	0	0
0	0	0	0	5.693	0	0	0	0	0	0	0
0	0	0	0	0	5.56	0	0	0	0	0	0
0	0	0	0	0	0	5.419	0	0	0	0	0
0	0	0	0	0	0	0	4.807	0	0	0	0
0	0	0	0	0	0	0	0	4.619	0	0	0
0	0	0	0	0	0	0	0	0	4.456	0	0
0	0	0	0	0	0	0	0	0	0	4.238	0
0	0	0	0	0	0	0	0	0	0	0	3.988

Classification Matrix (difference matrix) for class 2 test image 5

1	2	3	4	5	6	7	8	9	10	11	12
15.82	12.18	14.55	13.95	0	17.62	17.86	15.64	15.55	18.87	18.96	11.53

Sorting Image Matrix for class 2 test image 5

1	2	3	4	5	6	7	8	9	10	11	12
5	12	2	4	3	9	8	1	6	7	10	11

Comments for class 2 test image 5: The nearest recognized image from database is 5 and the Euclidian distance for it is 0 which is minimum as compared to other values. The sorted image number is 5. The test image is seen as a good tire and the classified image is also a good tire and hence the life span is approximated up to 80,000 miles to 100,000 miles with thread width of 10/32” to 11/32”and the temperature ranges from is 29.1^0C to 38.7^0C.

The following table gives out the parametric ranges observed physically (Temperature), Taken from standards (Thread Width) and Gray level or singular values from simulation using Matlab considering database and test images.

Table 3: Observed Analysis Table

Tire Type	Thread Width	Temp	Gray Level Variation	Usefulness or Life Span
Good Tire	10/32" to 11/32"	29.1^0 C - 38.7^0 C	21.88- 35.02	80,000 miles to 100,000 miles
Average Deformed Tire	6/32" to 8/32"	40.5^0 C – 45.3^0 C	38.77- 65.75	30,000 miles to 50,000 miles
Badly Deformed Tire	2/32" of remaining tread depth	46.2^0 C – 49.9^0 C	47.03- 67.9	30,000 miles

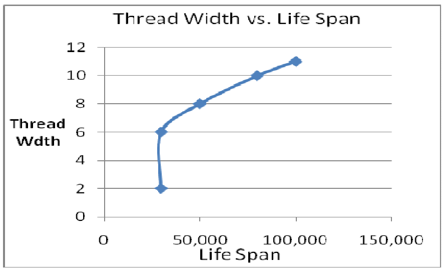


Chart 1: Thread Width vs. Life Span

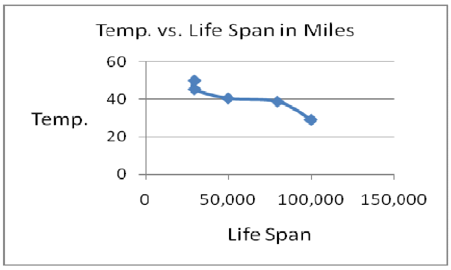


Chart 2: Temperature vs. Life Span

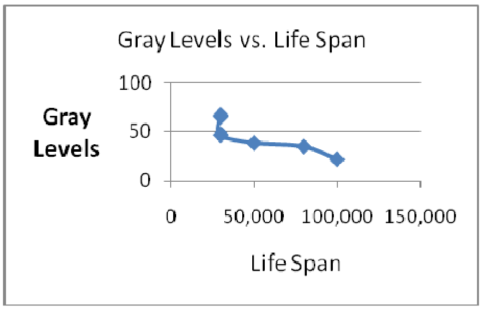


Chart 3: Gray Level vs. Lfe Span

CONCLUSIONS

Large databases can be maintained and tires can be classified accordingly by using a simple algorithm. The advent of soft computing can be used beyond the limits of thinking as nowadays Neural Network is extensively and intelligently used to study the human mind and researchers are giving advanced idea what the man can do in future and how he behaves in near future, Such is the case of Automobile Industry too wherein dependence of heavy machinery can be avoided by using Image processing technique. The non-destructive testing does require skilled Manpower to operate heavy machinery and to go through numerical aspects. The machinery used to assess mechanical components and elements usefulness are not user friendly. A robust attempt has been made here wherein machine dependence and little skills are enough to carry out life span calculations of the mechanical elements. Singular value decomposition algorithm is used on matlab platform to increase the prediction and analysis time wherein simulated results give at a glance the working condition of the components. By maintaining large databases, the accuracy can be increased by applying this methodology.

REFERENCES

1. *Sang Bock Lee "Image Processing Algorithms for Non-destructive Testing". Journal of the Korea Society of Computer and Information, Vol. 21 No. 9, pp. 45-49, September 2016.*

2. *Sze-Wei Khoo et al., "A review on surface deformation and strain measurement using two- dimanentional difital image correlation", Metrology and Measurement Sytems, Vol. 23(2016), No. 3, pp 461-480.*

3. *Khalid B. Najim, "Can Image Processing Technique Be Used as a Non-destructive Test in predicting Concrete Compressive Strength " Research Gate, February 2016.*

4. *M. J. Islam, M. Ahmadi, M. A. Sid-Ahmed, 'Image Processing Techniques for Quality Inspection of Gelatin Capsules in Pharmaceutical Applications,'' 10th Intl. Conf. on Control, Automation, Robotics and Vision Hanoi, Vietnam, 17–20 December 2008.*

5. *A Georgieva and I Jordanov, "image processing techniques for cork tiles classification "IEEE International Conference on Signal Processing and Communications (ICSPC 2007), 24-27 November 2007, Dubai, United Arab Emirates.*

6. *Yair Wiseman, "Take a Picture of Your Tire", Computer Science Department, Holon Institute of Technology, Israel*

7. *Francesco Braghin, Federico Cheli, Stefano Melzi and Ferrucco Resta," Tire wear model: Validation and Sensitivity Analysis", Springer 2006.*

8. *Fanzhu Li, Jun Liu, Haibo Yang, Yonglai Lu, Liqun Zhang, " Numerical simulation and experimental verification of heat build- up for rubber compounds", Science Direct Polymer 101 (2016) 199e207.*

9. *Shingo Futamura, Arthur A. Goldstein," prediction and simulation of tire performance characteristics based on deformation index concept", rubber chemistry and technology.*

10. *Yeong-Jyh Lin, Sheng-Jye Hwang," Temperature prediction of rolling tires by computer simulation", Science Direct Mathematics and Computers in Simulation 67 (2004) 235–249.*

11. *Michael Y. Y. Hung, "Shearography and Applications in Nondestructive Evaluation", Manufacturing Engineering & Engineering Management Department City University of Hong Kong, Hong Kong.*

12. *P. Huke, R. Klattenhoff, C. von Kopylow, R. B. Bergmann," Novel trends in optical non- destructive testing methods", J. Europ. Opt. Soc. Rap. Public. 83043, 2013.*

13. *Priyanka Khandelawal et al., "Mechanical part surface defect detection using crack extraction approach"", International Journal of Computer Applications, Vol. 100, No. 18, August 2014. pp 13-17.*

14. *Fein, H. (1997), "Holographic Interferometry: Non- destructive tool". The Industrial Physicist, American Institute of Physics.*

15. *E. Davies, Machine vision: theory, algorithms, practicalities. Morgan Kaufmann, 2005.*

16. *M. Egmont-Petersen, D. Ridder, and H. Handels, "Image processing with neural networks - a review", Pattern recognition, vol. 35, pp. 2279-2301, 2002.*

17. *M. Sonka, V. Hlavac, and R. Boyle," Image Processing, Analysis, and Machine Vision", Brooks/Cole Publ., 1999.*

18. *Michel Gre´diac, "The use of full-field measurement methods in composite material characterization: interest and limitations", Composites: Part A 35 (2004) 751– 761, Elsevier.*

19. *Pan, B., Qian, K., Xie, H., Asundi, A. (2009), "Two- dimensional digital image correlation for in-plane displacement and strain measurement: A review measurement" Sci. and Tech., 20(6), 1−17.*

20. *Sutton, M. A. (2008), "Digital image correlation for shape and deformation measurements", Handbook of Experimental Solid Mechanics. New York: Springer.*

21. *Sutton, MA. Orteu, J. J., Schreier, H. W. (2009). DIC, "Image Correlation for shape, Motion and Deformation Measurements: Basic Concepts, Theory and Applictions" New York: Springer, 83.*
22. *Giachetti, A. (2000), "Matching techniques to compute image motion". Image Vis. Comput., 18, 247−260.*
23. *Sutton, M. A., Orteu, J. J., Schreier, H. W. (2009). DIC, "Image Correlation for shape, Motion and Deformation Measurements:Basic Concepts, Theory and Applcations" New York: Springer, 95.*
24. *Chu, T. C., Ranson, W. F., Sutton, M. A., Peters, W. H. (1985), "Applications of digital image correlation techniques to experimental mechanics, Experimental Mechanics, 25 (3), 232−244.*
25. *Glover, C., Jones, H. (1994), "Stress, strain and deformation in solids. Conservation Principles of Continuous Media". Texas:McGraw-Hill.*
26. *Guo, X., Liang, J., Xiao, Z. Z., Cao, B. B. (2014), "Digital image correlation for large deformation applied in Ti alloy compressionand tension test". Optik, 125(18), 5316−5322.*
27. *Mathworks, Integral Image. (2012). athworks.com/help/vision/ref/integralimage.html*
28. *McNeill, S. R., Sutton, M. A., Miao, Z., Ma, J. (1997), "Measurement of surface profile using digital image correlation", Experimental Mechanics, 37(1), 13−20*
29. *K. R Mak P. Peng and H. YK. Lau, "A real time computer vision systems for detecting defects in textile fabrics", IEEE International Conference on Industrial Technology, pp. 469-474, 2005.*
30. *Z. Hong," Algebraic feature extraction of image for recognition," Pattern Recognition", 24 (1991) 211–219.*
31. *J. Ye,"Generalized low rank approximation of matrices", in: Int. Confe. On Machine Learning, pp. 2004, pp. 887–894.*
32. *B. Le Roux and H. Rouanet, Geometric Data Analysis. New York: Springer- Verlag, 2004.*
33. *J. M. Gilbert, B. Ananthasayanan, P. F. Joseph, T. B. Rhyne, and S. M. Cron, Tire Sci. Technol. 41, 82 (2013).*
34. *S. Futamura, T. G. Ebbott, A. A. Goldstein, L. R. Hischfelt, and R. L. Hohman, ''Determination of 'Deformation Index' of Tire Component by FEA,'' Tire Science and Technology, City, April 28–29, 1998.*